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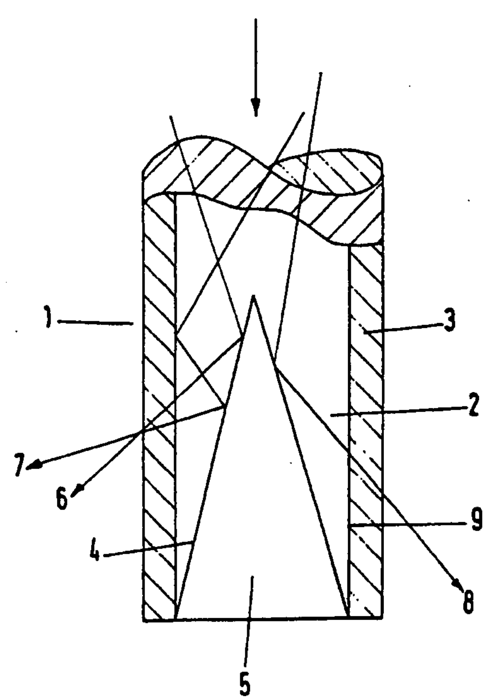
(54) Fibre optical waveguide for the radiate irradiation of tubular hollow systems by laser beams

(57) A fibre optical waveguide having a core region (2) and a casing (3). For the purpose of radiate irradiation of tubular hollow systems by laser beams introduced axially at one of its ends, at least one reflecting surface (4) is provided at the exit end of the waveguide. The reflecting surface (4) formed in the core region (2) and delimits a hollow space (5), open towards the exit end, in the core region (2).

Fig.1



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Fibre Optical Waveguide for the Radiate Irradiation of Tubular Hollow Systems by Laser Beams

The invention relates to a fibre optical waveguide having a core region and a casing, this fibre optical waveguide being provided, for the purpose of radiate irradiation of tubular hollow systems by laser beams introduced axially at one of its ends, with at least one reflecting surface at its exit end, and to a process for its production.

The method of radiate irradiation of tubular hollow systems, in particular those of narrow lumen, by laser beams is used not only in technology but also frequently in medicine, in particular in laser balloon angioplasty in the rechannelling and dilation of narrowed blood vessels by heat coagulation.

In this method, during the opening or expanding of closed or narrowed blood vessels by means of a balloon catheter, in the region of the balloon the surrounding expanded vessel wall is heat bonded by laser beams, as a result of which the danger of renewed closing is considerably reduced. The laser beams are guided in the catheter, through a fibre optical waveguide ending in the balloon, to the vessel area to be irradiated, in which case the exit end of the fibre optical waveguide must be prepared such that a uniform radiate radiation of the laser beams is effected.

One possibility of achieving uniform radiate radiation consists in providing the exit end of the fibre optical waveguide with suitable scattering bodies.

Such a measure is described in WO85/05262. WO85/05262 relates to a laser probe which is particularly suitable for surgical applications. This laser probe

substantially comprises a fibre optical waveguide which guides the laser beams from a laser to a sapphire body which is optically coupled to the other end of the fibre optical waveguide and is conically chamfered in the direction of radiation and within which the laser beams are focused using total reflection at the cone walls before they emerge at the cone tip. In a particular embodiment, WO85/05262 provides for the formation at the cone tip of a further substantially ball-shaped section comprising a sapphire material having scattering centres in the form of finely divided gas bubbles, as a result of which, depending on the geometry of the arrangement, the angle of divergence of the radiation emerging from the sapphire tip can be increased as desired.

A disadvantage of this arrangement consists, however, in the fact that securing and optical coupling of the sapphire tip to the fibre end is difficult and technically complicated. In particular, it is associated with a perceptible widening in the diameter of the laser probe. Moreover, there is an increased danger of breakage in the coupling region of the flexible fibre optical waveguide and the rigid sapphire tip, as a result of which applications requiring a flexible guidance of the laser probe in curved hollow systems are not possible.

The above-mentioned disadvantages are partly remedied by the arrangement known from British Patent 1154761 A, which is distinguished by the fact that a uniform radiate radiation is achieved by the core region of the fibre optical waveguide itself being shaped to form a cone at the exit end, but in contrast to the arrangement from WO85/05262 the geometry of the cone is selected such that the laser beams are not focused towards the fibre tip but are radiated over the entire cone surface radiately outwards.

However, in practice the fibre optical waveguides prepared in this manner display a high susceptibility to mechanical stress, in particular in the region of their unprotected cone tip, so that even with careful handling frequent breakages must be expected. When used in the medical field, the result is an unreasonable strain on the patient. However, even with other applications the associated additional expense for time, materials and work make the use of such a fibre optical waveguide unviable.

It is the object of the present invention to provide a fibre optical waveguide of the type described at the outset which does not have the disadvantages described above, and to make available a process for its production.

According to the present invention, there is provided a fibre optical waveguide having a core region, a casing, and at least one reflecting surface at an exit end of the waveguide, said at least one reflecting surface being provided for the purpose of radiate irradiation of a tubular hollow system by laser beams introduced axially at one of its ends, wherein the reflecting surface is formed in the core region of the fibre optical waveguide and delimits a hollow space, open towards the exit end, in the core region.

The fibre optical waveguide according to the invention is distinguished by a resistance to breakage and bending which is increased by comparison with the prior art, since the casing surrounding and protecting the core region remains intact over the entire length of the fibre optical waveguide, even in the region of the exit end.

In a preferred embodiment of the invention, the

hollow space, delimited by the reflecting surface, in the core region of the fibre optical waveguide has the shape of a cone whereof the base faces the exit end of the waveguide. Such an inner cone has the advantage of a much higher mechanical stability by comparison with the outer cone known from the prior art, effected by a higher angular impulse or polar moment of inertia.

When using a full-core fibre optical waveguide, a good reflective action is achieved if the aperture angle of the cone is between 45° and 90°. In accordance with the invention, it is preferred that the height of the cone does not exceed 2 mm in order that good mechanical stability is ensured. Because of its good optical and physical properties, a quartz glass fibre having a core diameter of 200 to 600 µm is preferably used.

However, the shape of the reflecting surface is in no way restricted to the cone casing described above.

In accordance with the invention, a surface of any desired shape is possible as long as it has the effect of a uniform outward radiate irradiation of the laser beam.

Because production is less problematic, reflecting surfaces having a continuous curvature are to be preferred over those with defined discontinuities such as, for example, points or edges. Such surfaces may for example be ellipsoidal, paraboloidal or spherical, but may also represent intermediate shapes of different geometric basic types.

A preferred embodiment of the invention provides for the reflecting surface to be shaped such that the hollow space in the core region of the fibre optical waveguide has the shape of a cone with a rounded off tip. This embodiment has the advantage that, on the one hand,

a uniform radiate irradiation of the laser beams is achieved and, on the other hand, complicated and expensive shaping of the cone tip during production is dispensed with.

To increase the scattering effect, in a further preferred embodiment of the invention, provision is made for the hollow space to be lined on its internal surface with a layer of reflecting or scattering material which does not absorb the laser radiation. From a manufacturing point of view, it is technically simple to line the hollow space for example with a metal film by means of vapour deposition, sputtering on or similar processes, or alternatively to apply a powder of a suitable material to the inner surface. It is particularly advantageous as regards the expense of applying a uniform powder layer simply to fill the entire hollow space with the powder.

Because of its high capacity for reflection, metal dust is particularly suitable for this purpose. In a preferred embodiment, the use of barium sulphate as the scattering material is provided, since its effect as an efficient phase scatterer is known and moreover it is very simple and cost-effective to produce.

The powder of reflecting or scattering material, placed in the hollow space, not only increases the scattering capacity but also the mechanical strength of the exit end of the fibre optical waveguide. Here, the powder layer or powder volume placed in the hollow space is also effectively protected from mechanical stress from the outside.

Preferably, the hollow space is closed at its open end by a small metal ball, as a result of which even that portion of the laser beams which still emerges from the

fibre end in the axial direction undergoes a backward reflection. In a preferred embodiment, a small gold ball is used because of its good resistance to corrosion.

The reflecting surfaces may in simple manner be formed in the core region of the fibre optical waveguide by means of laser material processing, preferably by means of a pulsed laser emitting in the UV range. Chemical etching processes are similarly suitable.

Preferably, the fibre optical waveguide according to the invention can be used in laser balloon angioplasty, in which case it is inserted into the central channel of a balloon catheter for heat bonding the expanded vessel wall in the region of the balloon by means of laser beams. The mechanical stability in conjunction with high flexibility and the particular radiation characteristic at the exit end make it suitable for this purpose, as does the significantly reduced danger of damage to the balloon material or the surrounding soft tissue by comparison with fibre optical waveguides having a sharp exit end, known from the prior art.

The fibre optical waveguide according to the invention is, however, not only of interest because of its use in angioplasty but can in particular also be used in the field of photodynamic therapy for the irradiation of multifocal tumours in narrow lumens or directly in palliative tumour rechannelling in the respiratory or digestive tract. Such a fibre optical waveguide is also of interest in the neurosurgical field.

The invention is described in more detail below with reference to various embodiments, in conjunction with the drawings.

Fig. 1 shows, in a diagrammatic illustration in longitudinal section, the exit end of a fibre optical waveguide which is provided in accordance with the invention with a conical hollow space and, by way of example, the beam path at the exit end of a few laser beams;

Fig. 2 shows, in a similar representation to Fig. 1, the exit end of a fibre optical waveguide, the reflecting surface being continuously curved at its apex;

Fig. 3 shows the same view as Fig. 1, the inner surface of the conical hollow space being lined with a layer of a powder of a scattering material;

Fig. 4 shows the same as Fig. 1 but with the conical hollow space being completely filled with a powder of a scattering material;

Fig. 5 shows the same as Fig. 1 but with the conical hollow space being closed at its open end by a small metal ball, and

Fig. 6 shows an example of use of the fibre optical waveguide, according to the invention, from Fig. 3 in balloon catheter angioplasty.

Fig. 1 shows the exit end for the laser beams of a fibre optical waveguide 1 according to the invention which has a core region 2 and a casing 3. The reflecting surface 4 delimits a hollow space 5 in the core region 2 of the fibre optical waveguide 1 which, in accordance with a preferred embodiment of the invention, has the shape of a cone. The arrow indicates the direction in which the laser beams enter. Laser beams 6, 7, 8 which are guided in the fibre optical waveguide 1 in the axial direction and impact against the reflecting surface 4 at

the exit end are totally reflected against this surface and emerge from the fibre optical waveguide sideways.

Fig. 3 illustrates the reflecting surface 4 lined with a powder of scattering material 10 for the purpose of increasing the scattering effect, as a result of which a laser beam 11 penetrating through the reflecting surface 4 into the hollow space 5 is scattered a plurality of times against the powder 10 before it emerges from the fibre optical waveguide.

In Fig. 4, the entire hollow space 5 is completely filled with the powder of scattering material 10. In particular, that portion of the laser beams which would otherwise still leave the fibre optical waveguide 1 at the exit end in the axial direction, as a result also undergoes a plurality of changes of direction, as indicated by the example of the laser beam 12.

Fig. 5 shows a further preferred embodiment of the invention. The conical hollow space 5 is in this embodiment closed by a small metal ball 16, as a result of which there is a backward reflection of all the laser beams emerging through the cone opening. This is illustrated by the example of the beam path of a laser beam 18.

Fig. 6 shows as an example of use of a fibre optical waveguide according to the invention its use in laser balloon angioplasty. A fibre optical waveguide 1 according to the invention, whereof the exit end 20 corresponds to the embodiment illustrated in Fig. 4, is introduced into the central channel of a balloon catheter 22 until the exit end is in the region of the balloon 24. The balloon catheter 22 is directed into the narrowed blood vessel 26, which is widened again by expansion of the balloon 24. In the region of the expanded balloon

24, the fibre optical waveguide 1 acted upon by laser radiation is moved to and fro, the laser radiation 28 was emitted radiately from the exit end 20 of the fibre optical waveguide 1 heat bonding the surrounding tissue 30 of the vessel wall 32.

A preferred embodiment of the invention will be described below with reference to an example embodiment.

A quartz glass fibre having an external diameter of 450 and a core diameter of 400 µm was used. The height of the cone, formed in the core region by means of a chemical etching process and having a rounded off tip, was 480 µm. The hollow space was filled with a powder of $BaSO_4$ and then closed by means of a small gold ball having a radius of 250 µm. The small gold ball was secured to the end of the fibre optical waveguide by means of an adhesive which is transparent to laser radiation.

Using the fibre optical waveguide end prepared as described above, good uniform radiate irradiation was achieved.

Claims

1. A fibre optical waveguide having a core region, a casing, and at least one reflecting surface at an exit end of the waveguide, said at least one reflecting surface being provided for the purpose of radiate irradiation of a tubular hollow system by laser beams introduced axially at one of its ends, wherein the reflecting surface is formed in the core region of the fibre optical waveguide and delimits a hollow space, open towards the exit end, in the core region.

2. A waveguide according to Claim 1, wherein the hollow space has the shape of a cone whereof the base faces the exit end.

3. A waveguide according to Claim 2, which is a full-core fibre optical waveguide, and wherein the aperture angle of the cone is between 45 and 90°.

4. A waveguide according to Claim 2 or 3, wherein the height of the cone is $\leq$ 2 mm.

5. A waveguide according to Claim 4, formed of quartz glass fibre, and wherein the diameter of the core region is between 200 and 600 µm.

6. A waveguide according to Claim 1, wherein the reflecting surface is continuously curved.

7. A waveguide according to any one of Claims 1 to 6, wherein the hollow space is lined on the inside with a layer of reflecting or scattering material which does not absorb the laser radiation.

8. A waveguide according to Claim 7, wherein said layer is a metal film.

9. A waveguide according to Claim 7, wherein said layer is of a reflecting or scattering powder.

10. A waveguide according to any one of Claims 1 to 6, wherein the hollow space is completely filled with a powder of a scattering or reflecting material which does not absorb the laser radiation.

11. A waveguide according to any one of Claims 9 or 10, wherein the reflecting powder is a metal dust.

12. A waveguide according to Claim 9 or 10, wherein the scattering powder is a barium sulphate powder.

13. A waveguide according to any preceding claim, wherein the hollow space is closed at its open end by a body of reflecting surface.

14. A waveguide according to Claim 13, wherein the body is a metal ball.

15. A waveguide according to Claim 14, wherein the metal is gold.

16. A fibre optical waveguide as claimed in Claim 1, substantially as hereinbefore described with reference to any one of Figures 1 to 4 of the accompanying drawings.

17. A process for producing a fibre optical waveguide according to any preceding claim, wherein the hollow space in the core region of the fibre optical waveguide is shaped by means of a pulsed laser emitting in the UV range.

18. A process for producing a fibre optical waveguide according to Claim 1, wherein the hollow space in the

core region of the fibre optical waveguide is produced by means of a chemical etching process.

19. A balloon catheter for laser balloon angioplasty, having a central channel in which a fibre optical waveguide as claimed in any one of claims 1 to 16 is introduced.

20. A balloon catheter as claimed in Claim 19, substantially as hereinbefore described with reference to Figure 5 of the accompanying drawings.

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Fig.1

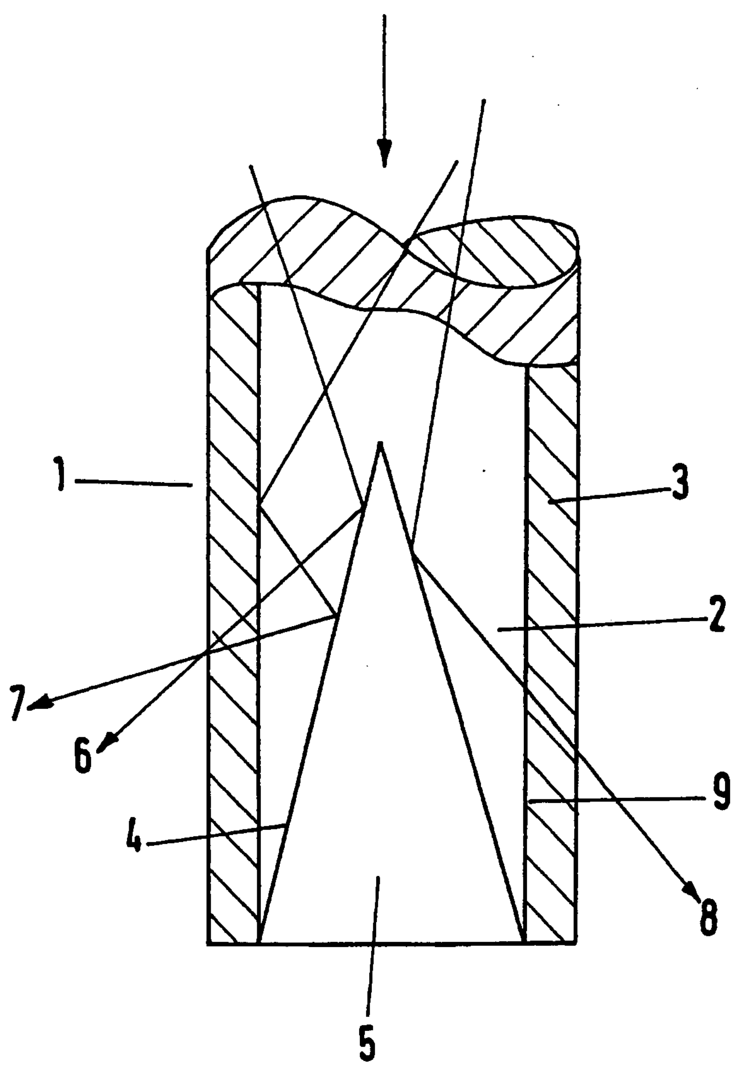

Fig.2

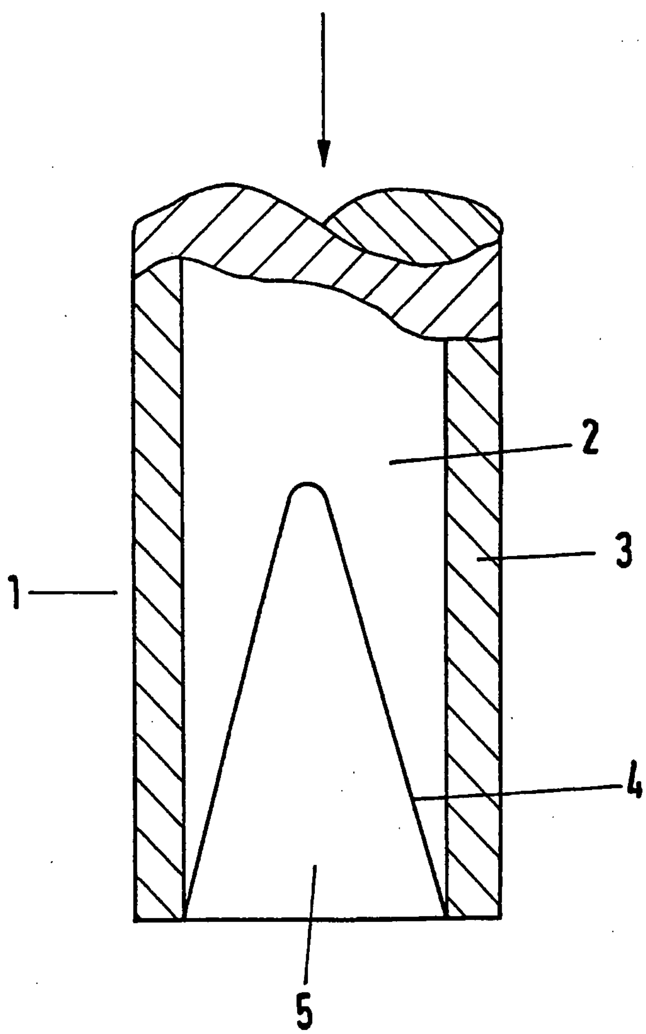

Fig.3

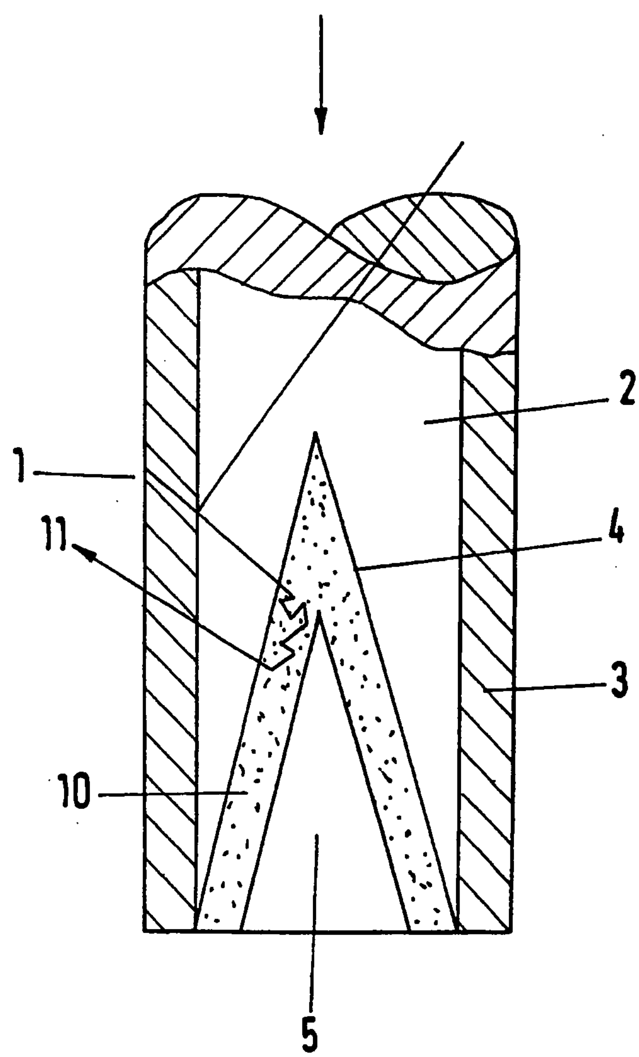

Fig.4

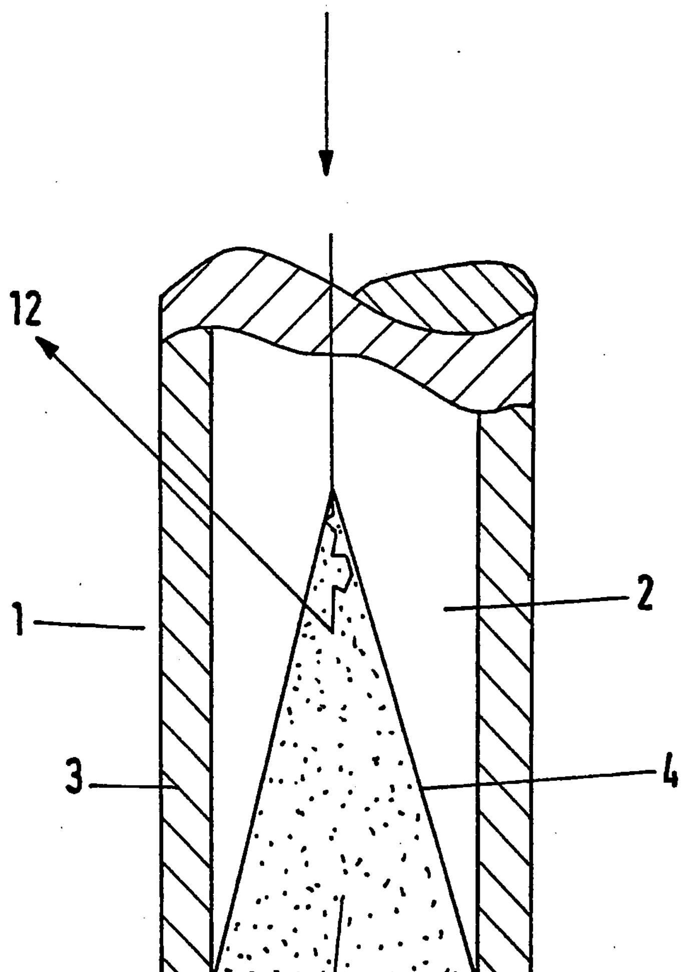

Fig.5

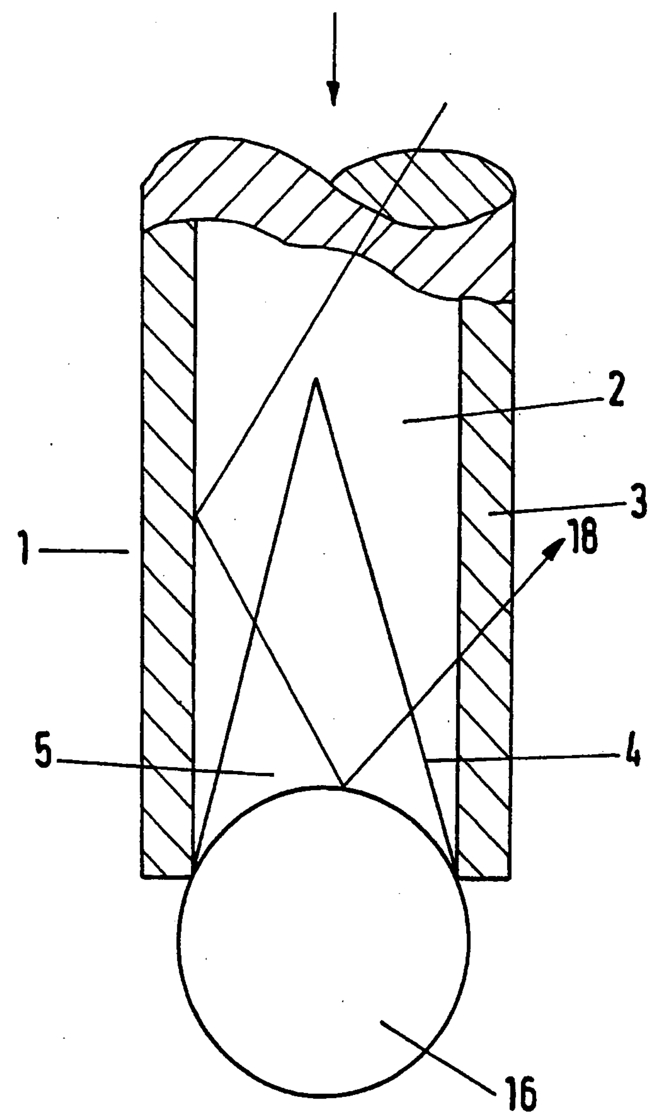

Fig.6